Wireless Power Transmission

Orders of Magnitude and General Parameters

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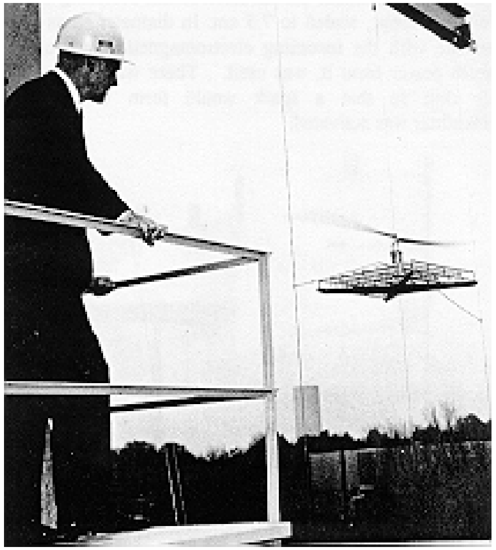
General Idea

- Definition: “*efficient* transmission of electric power from one point to another through the vacuum or an atmosphere without the use of wire or any other substance” (W. Brown)
- Two main methods:
  - Via microwave frequencies (some GHz, typically: 2.45; 5.8)
  - Via optical frequencies (laser)
- Main parts (microwave option):
  - d.c. to to microwave power conversion
  - Transmitting antenna forms a (narrow) beam
  - Absorption and reconversion at receiving antenna (microwave to d.c.)
- Main motivations (currently):
  - Research on Solar Power Satellites
  - (power relay satellites)
  - Power for space exploration (alternative to space nuclear power sources?)

Short Historical Flash

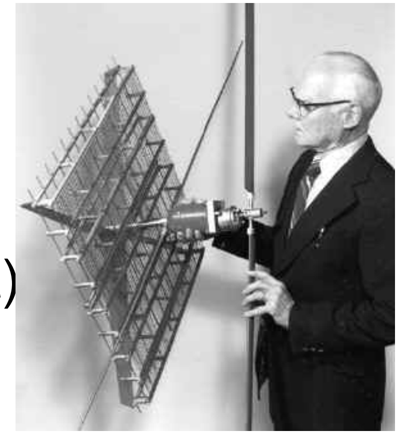
- Physical origins:
  - 1873: Maxwell predicts energy transport via electromagnetic waves through vacuum
  - 1885-89: Hertz validates Maxwell's predictions
  - 1899-1910: Tesla made (unsuccessful) wireless power transmission experiments
  - Worldwar II: availability of high power microwave beams (parabolic dishes etc.)
- Demonstrations:
  - **1963: 1st d.c. to d.c. system, ε=13%**
  - **1964: microwave powered helicopter** (Raytheon Comp.)
  - Theoretical work showed max. efficiency almost 100%
  - 1964: reflected beam efficiency measured at 99% (λ=4m)
  - Demonstration and further funding by von Braun (MSFC as lead)
  - 1974: d.c. to d.c. system ε=26%, then 39%
  - 1975: d.c. to d.c. system ε=54%



Short Historical Flash (cont.)

- 1975: 1st large scale experiment at JPL facility at Mojave desert:

  transmission of 30 kW over 1.4 km
- 1976: receiving antenna efficiency of 91%
- 1983: Japanese MINIX experiment: wireless power transmission in ionsphere (sounding rocket) (ISAS+Kyoto Univ.)
- 1987: mircowave powered aircraft demonstration in Canada (SHARP)
- 1993: microwave powered aircraft demonstration (Kyoto Univ.)
- 1993: Japanese ISY-METS experiment: WPT in ionsphere (ISAS+Kyoto Univ.)
- 1998: French WPT experiment in La Réunion

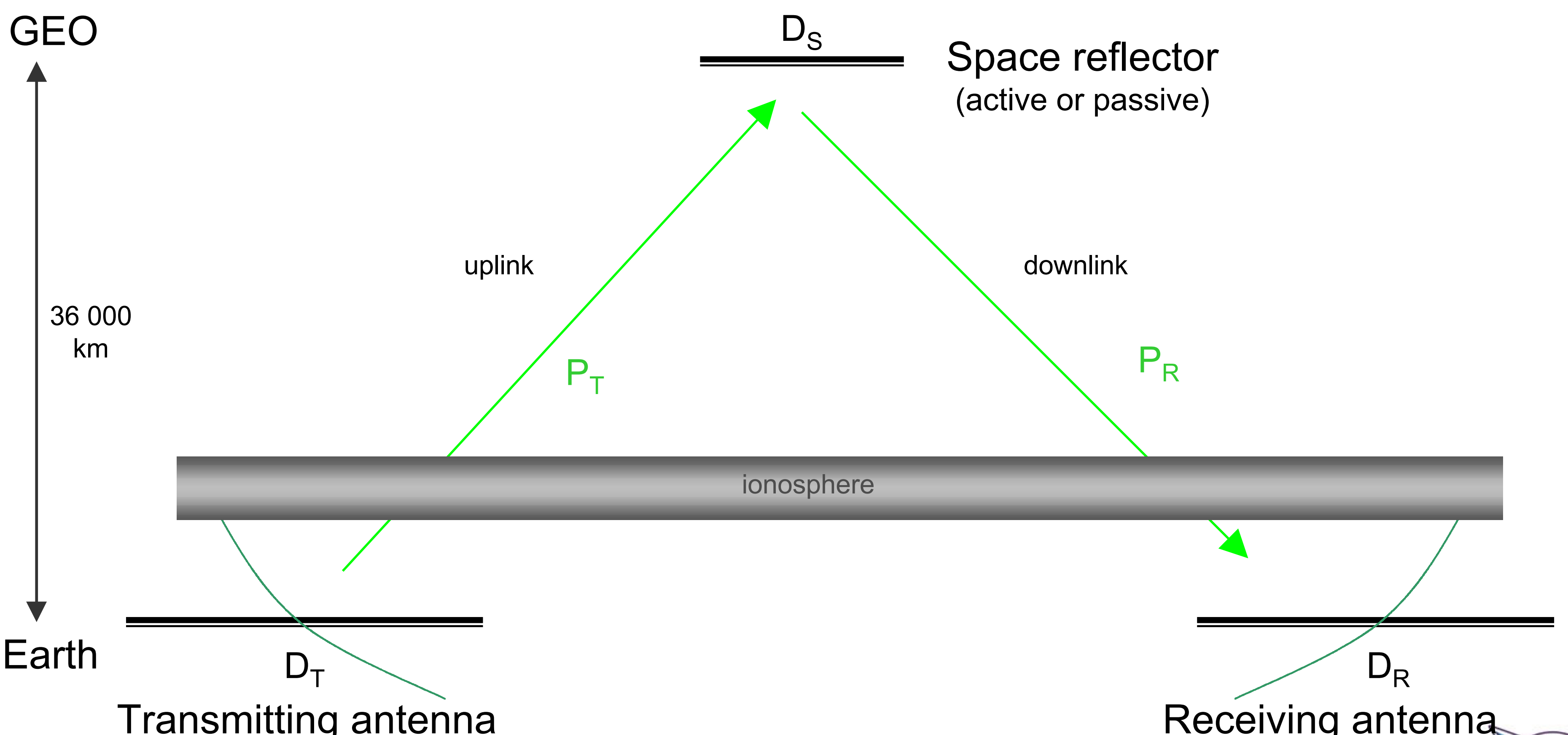


Earth-Space-Earth Power Relay

- Today: only limited transport of large quantities of electric energy over large distances – locally produced and used (fossil energy vectors for energy transport)
- Future:
  - potentially “cleaner” energy vectors: *hydrogen* and *electricity*
  - Possibly combination of distributed, delocalized and large-scale centralised energy generation (nuclear power stations and solar power plants
    (“mixtribution”)

    ⇨ necessity for efficient long distance energy transport systems.

Schematic View of a Space Power Relay Satellite



Constraints

- Only certain frequencies possible (atmospheric, ionospheric interactions)
  - Studies with 2.45 (and 5.8) GHz
- At 2.45 GHz, no ionospheric interactions only at power densities <230 W/m^2
- Max. power densities at space reflectors about 30 (possibly 90) kW/m^2 (material limitations – cooling issue)
- Max. beam efficiencies: 97% (Gauss shaped beams), 82.6% for uniform transmission antenna excitation
- Max. power densities at ground cites due to environmental and safety restrictions ~200-300 W/m^2 (in centre, ca. 10 W/m^2 at edge)

Orders of Magnitude

calculations for antenna-reflector-receiver diameters

	Transm. Ant.	Reflector	Receiving Ant.	
opt. beam eff. (2x Gauss shaped beams)	D=10.6 km 8.1 GW	D=1.02 km 7.9 GW	D=10.2 km 7.7 GW	Gauss shaped transmitting beam tot. beam eff.: 95%
unif. transm. beam (1 Gauss shaped beam)	D=7.5 km 13.2 GW	D=1.18 km 10.9 GW	D=8.9 km 10.6 GW	Uniform transmitting beam; Gauss shaped receiving beam tot. beam eff.: 80%
Radial polarisation excitation	D=13 km 19.6 GW	D=1.3 km 19.4 GW	D=13.1 km 19 GW	tot. beam eff.: 97%

Very preliminary cost estimations

- Transmission antenna costs higher than receiving antenna costs
- space segment:
  - Two possibilities: (est. of 1980 techn.)
    - Metallic mesh reflector (MMR) – 1 kg/m^2
    - Active phased antenna array (APA) – 20 kg/m^2
- Japanese cost estimates:
  - Total system costs: MMR: ~40-100 B€
    APA: ~11-20 B€
  - Specific costs: MMR: ~2.4-5 €cts/kWh
    APA: ~6.6-9 €cts/kWh

Major Issues

- Earth-to-Space transportation system
- Phase disturbance of microwave beam in ionosphere
- Large emitter and receiver antenna sizes
- Frequency issues (sidespills, compliance with ITU regulations)
- Laser power transmission still very inefficient but increasingly interesting (rapid and important current development)
- Public/political acceptance of microwave power transmission presence
- Beam steering and controlling issues